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USAFSAM-TP-89-10

THERMAL EVALUATION OF TWO PROTOTYPE AIRCREW CHEMICAL DEFENSE ENSEMBLES

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August 1989

Interim Report for Period 1 October 1987 - 31 December 1987

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USAF SCHOOL OF AEROSPACE MEDICINE
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NOTICES

This interim report was submitted by personnel of the Chemical Defense Branch, Crew Technology Division, USAF School of Aerospace Medicine, Human Systems Division, AFSC, Brooks Air Force Base, Texas, under job order 2729-04-04.

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The voluntary fully informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): USAFSAM-TP-89-10	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: USAF School of Aerospace Medicine; 6b. OFFICE SYMBOL (If applicable): USAFSAM/VNC	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Human Systems Division (AFSC) Brooks AFB, TX 78235-5301	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: USAF School of Aerospace Medicine; 8b. OFFICE SYMBOL (If applicable): USAFSAM/VNC	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Human Systems Division (AFSC) Brooks AFB, TX 78235-5301	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 62202F; PROJECT NO. 2729; TASK NO. 04; WORK UNIT ACCESSION NO. 04

11. TITLE (Include Security Classification)

Thermal Evaluation of Two Prototype Aircrew Chemical Defense Ensembles

12. PERSONAL AUTHOR(S)

Krock, Larry P.; Garza, John R.; and Wiegman, Janet

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM 87/10/01 TO 87/12/31	1989, August	19

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
06	07	
15	06	03

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Aircrew Chemical Defense Ensemble; Gentex Intimate Blend Coverall; thermal stress; Winfield Monopack Saratoga Coverall.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Individual aircrew members are protected against chemical warfare environments by the Aircrew Chemical Defense Ensemble (ACDE). The current regulation ACDE (flight suit coverall worn over an activated charcoal undergarment) inhibits dissipation of body heat, resulting in severe physiological limitations on task performance. Several second-generation ACDE prototype designs are undergoing review by the U.S. Air Force Life Support System Program Office. Two of these candidate ACDEs were compared to the current ACDE with respect to thermal stress associated with task performance. The two ACDEs evaluated were: the Gentex Intimate Blend Coverall, and the Winfield Monopack Saratoga Coverall. Human subjects were instrumented; they then dressed in the experimental ACDE plus flight safety equipment, and performed scheduled tasks in a climate-controlled chamber at the U.S. Air Force School of Aerospace Medicine, Brooks AFB, Texas. To initiate the experiment, subjects pedaled on an ergometer (50 W) for 10 min, after which they sat in a high-performance aircraft ejection seat and performed minimal physical activities for 1 h; following this seated phase, the subjects again pedaled the ergometer (50 W) for 30 min. Heart rates, core (rectal) temperatures, and 5 skin temperatures (chest, back, upper

(cont'd. on p. ii)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Larry P. Krock, Ph.D.	22b. TELEPHONE (Include Area Code): (512) 536-3521; 22c. OFFICE SYMBOL: USAFSAM/VNC

DD Form 1473, JUN 86 — Previous editions are obsolete. — SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

19. ABSTRACT (Continued)

arm, upper leg, and calf) were measured at 30-s intervals throughout the experiment. To measure sweat production and sweat evaporation, the subjects were weighed, both nude and fully dressed, immediately before and after the experiment. Temperature and heart rate data, averaged over the last 5 min of each phase, were subjected to a three-way, mixed-model analysis of variance with repeated measures. Under the conditions of these experiments, the candidate second-generation aircrew chemical defense ensembles (Gentex and Winfield) did not differ significantly from the current ACDE. (U)

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THERMAL EVALUATION OF TWO PROTOTYPE AIRCREW CHEMICAL DEFENSE ENSEMBLES

INTRODUCTION

Aircrews could be required to operate in chemical warfare environments. Protection from life-threatening chemical agents must be provided to individual aircrew personnel throughout mission operations and during transition to and from aircraft and collective protection shelters. This individual protection is provided by the Aircrew Chemical Defense Ensemble (ACDE).

The current ACDE, which consists of a flight suit coverall worn over an activated charcoal undergarment, inhibits dissipation of body heat--thus imposing severe physiological limitations on task performance. Second-generation ACDE prototypes are under review by the U.S. Air Force (USAF) Life Support System Program Office as replacements for the current ACDE. Significant among the changes incorporated in these prototype ensembles is the integration of the charcoal protective layer into the flight suit coverall, giving a single-layer design. The combination of layers, although apparently increasing the thickness ("heaviness") of the coverall, would reduce--or at least make no worse--the thermal burden.

The objective of the present study was to evaluate, in humans, the thermal stress profile produced by each of two candidate ACDEs and to compare each prototype's thermal stress profile to that produced by the current ACDE.

EQUIPMENT AND PROCEDURES

Equipment

Thermal-stress evaluation in human subjects was conducted in a climate-controlled chamber at the USAF School of Aerospace Medicine (USAFSAM), Brooks AFB, Texas, during December 1987. The steel-walled climate-controlled research chamber has an interior volume of 17.0 m^3 (600 ft^3); it can be varied and controlled over wide ranges of temperature and humidity.

The three ACDEs evaluated in this study were: a) the current regulation ACDE, consisting of a Nomex flight suit worn over the United Kingdom charcoal undergarment (Fig. 1); b) the Gentex Intimate Blend Coverall; and c) the Winfield Monopack Saratoga Coverall. The Gentex and Winfield Coveralls (CWU-66/P) are shown in Figure 2.

The wear configuration for all experiments was identical, except for the designated ACDE coverall. From the skin out, subjects wore cotton long sleeve undershirt, cotton full-legged underpants, designated ACDE, survival vest (LPV-9/P), parachute harness, anti-G suit, aircrew mask (MBU-13/P CBO), butyl rubber hood

(HGU-41/P), aircrew chemical defense glove set (cotton insert, 7-mil butyl rubber and Nomex flight gloves), cotton socks, and flight boots. A subject wearing a complete assembly (Gentex ACDE) is shown in Figure 3. The aircrew helmet (HGU SS/P) and breathing air filter were not worn during the measurements because they caused considerable subject discomfort and could have adversely affected the outcome of the experiment.

Figure 1. The current Aircrew Chemical Defense Ensemble.

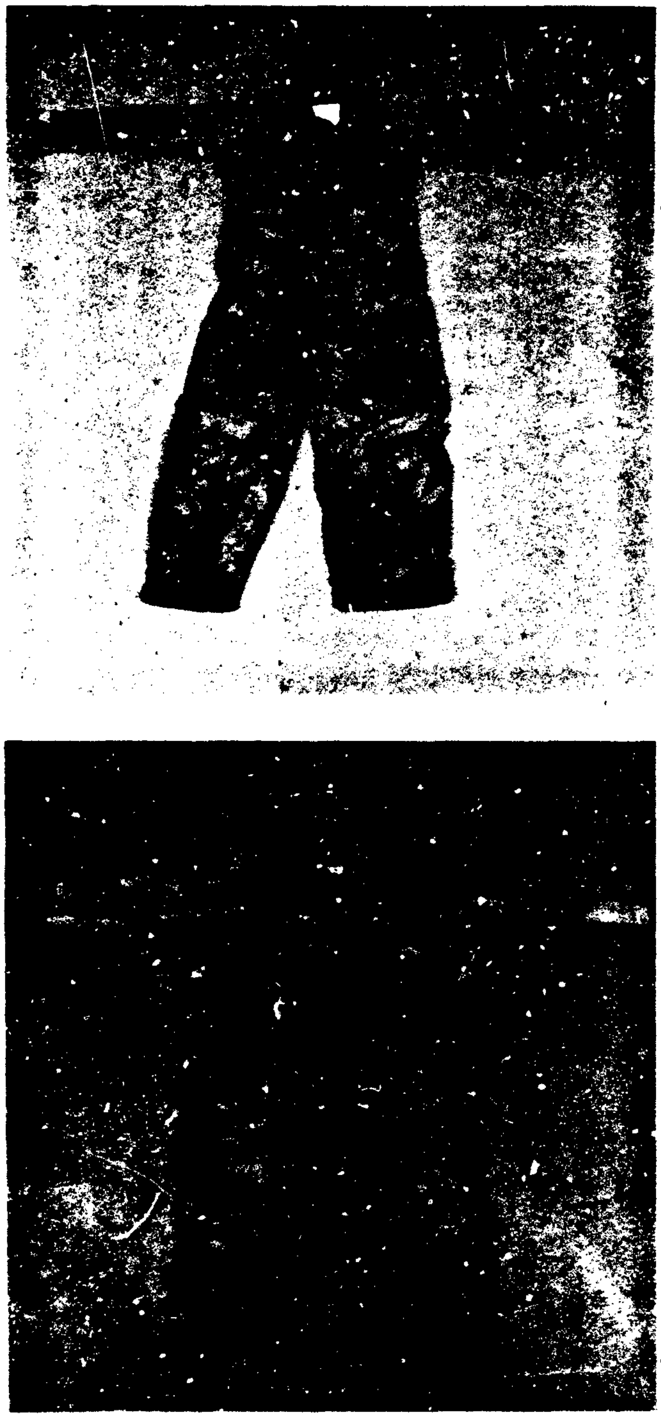

Figure 2. The two prototype evaluated ACDEs: Gentex (top), and Winfield (bottom).

Figure 3. Subject wearing the Gentex ACDE plus additional aircrew equipment. The Winfield and current ACDEs were configured similarly for thermal experiments.

Procedures

Six healthy volunteers from the existing USAFSAM thermal subject pool participated in this study. General characteristics of the subjects are given in Table 1.

TABLE 1. CHARACTERISTICS OF SUBJECTS

Subject	Sex	Age (y)	Height cm	Height (in.)	Weight kg	Weight (lb)
1	M	39	180.3	(71.0)	83.1	(182.7)
2	M	39	171.5	(67.5)	78.8	(173.4)
3	F	24	175.3	(69.0)	65.2	(143.4)
4	M	38	176.5	(69.5)	85.9	(189.0)
5	F	24	172.7	(68.0)	67.6	(148.8)
6	M	29	170.2	(67.0)	74.9	(164.8)
	Mean:	*32.2*	*174.4*	*(68.6)*	*75.9*	*(167.0)*

In compliance with AFR 169-3, after the subjects were briefed on the nature and objective of this investigation, they gave their voluntary, informed, written consent to participate in the study. The subjects reported to the laboratory in a rested state 1 h prior to the session. After being weighed nude and instrumented, each subject donned the designated ACDE ensemble flight equipment and was weighed again, fully dressed.

Instrumentation of subjects (Fig. 4) consisted of the following: 3 electrocardiographic electrodes for recording heart rates with a Transkinetics telemetry system; rectal thermistor (Yellow Springs Instruments, 701) inserted 10 cm for monitoring core temperature; and 5 skin thermistors (Yellow Springs Instruments, 709B) located on the chest, back, upper arm, upper leg, and calf, from which a mean skin temperature was calculated using Ramanathan's formula:

$$\bar{T}_s = [0.3(T_{chest} + T_{arm}) + 0.2(T_{thigh} + T_{leg})] \quad (1).$$

Heart rate and temperature data were collected in real time at 30-s intervals employing a Digital Equipment Corporation 11/23 computer. These data were later reduced and reported as means for 5-min intervals. After recording the dressed weight (Fig. 5) and performing a final check of the telemetry and thermistor equipment function, the subject was led to the environmental chamber and seated on the cycle ergometer (Monarch, model 368) shown in Figure 6.

Mean (± SD) environmental conditions during the chamber tests were: dry bulb, 40.2 ± 1.2 °C; wet bulb, 23.8 ± 1.2 °C; and black globe, 45.0 ± 1.6 °C. The variability in chamber environmental conditions was not statistically significant ($p > 0.05$).

While the subject sat quietly upon the ergometer, baseline recordings were obtained. The initial exercise period began when the subject commenced pedaling the ergometer (50 W). This pre-flight work simulation continued for 10 min, whereupon the subject ceased pedaling and moved to sit in a high-performance aircraft ejection seat located adjacent to the ergometer in the environmental chamber (Fig. 7). The subject remained seated while performing minimal physical activities (i.e., reading,

puzzle solving, note taking, etc.) for 1 h, then returned to the cycle ergometer for an extended ride of 30 min (50 W). At the end of the exercise phase, the subject was immediately weighed, both fully dressed and nude. The total volume of sweat produced, sweat rate, sweat evaporation and percent evaporation of the sweat produced were calculated from the pre- and post-session weights.

All subjects experienced all three experimental conditions (ACDEs); a minimum rest of 1 day was given between exposures. A randomized counter-balanced design was used to assign the ensemble-wear order to eliminate any possible order-related bias of results.

Temperature and heart rate data for the final 5-min interval of each phase (baseline, exercise, seated, exercise) of the experimental protocol were subjected to a three-way, mixed-model analysis of variance with repeated measures.

RESULTS

Core temperature

The core temperature data for the three phases of the protocol are summarized in Figure 8. The changes in core temperature during the experiment were 0.7 °C (1.3 °F), 0.8 °C (1.4 °F), and 0.6 °C (1.1 °F), for the current, Gentex, and Winfield ACDEs, respectively. Core temperatures were not significantly different between ensembles at the end of the session.

Mean skin temperature

Figure 9 summarizes the mean skin temperatures calculated as weighted averages of four skin temperatures. The average change in mean skin temperature from the beginning to the end of the experiment was 2.9 °C (5.2 °F); this change was not significantly different among the three ACDEs.

Figure 4. Instrumentation of subject with electrocardiographic electrodes and various thermistors.

Figure 5. Measurement of subject "dressed weight."

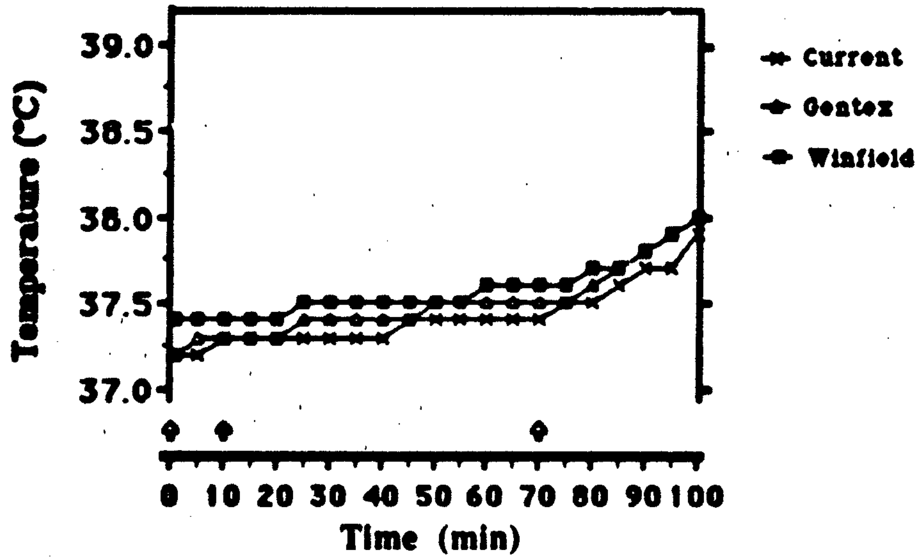

Figure 8. Mean core temperatures for the three ensembles (N = 6). Open arrows indicate beginning of exercise phase (50 W); closed arrow, beginning of sitting phase.

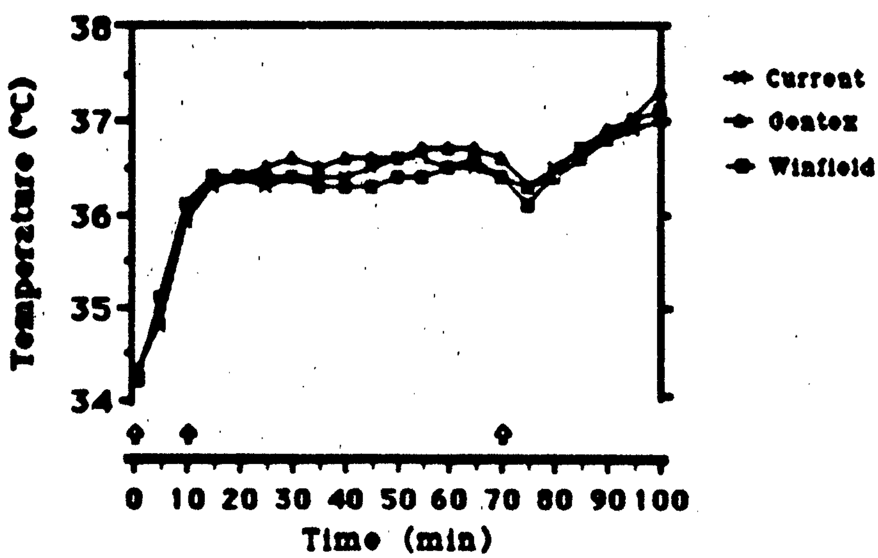

Figure 9. Ensemble mean (N = 6) values of mean skin temperatures. Open arrows indicate beginning of exercise phase (50 W); closed arrow, beginning of sitting phase.

Heart rata

Figure 10 displays the 5-min averages for heart rates throughout the experiment. There was an initial rise in heart rate with the onset of exercise; the rate then decreased and remained relatively stable at the lower level throughout the sitting (simulated flight) phase of the protocol. The subjects exercised again at 70 min into the test protocol; this exertion is reflected by the rapid increase in rate (Fig. 10). For given time intervals, the mean heart rates among ACDEs were remarkably similar throughout the protocol.

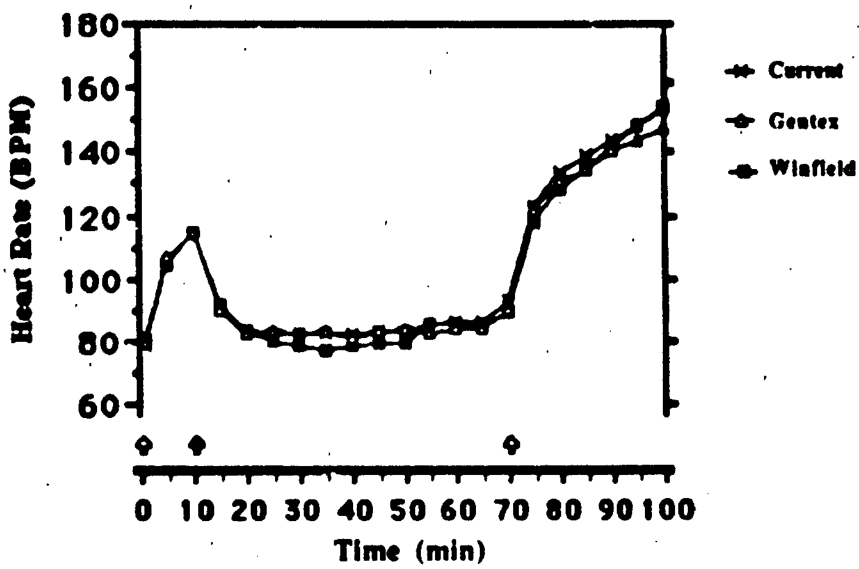

Figure 10. Ensemble mean (N = 6) heart rates. Open arrows indicate beginning of exercise phase (50 W); closed arrow, beginning of sitting phase.

Thermal sweating

The mean (by ensemble) values for sweat production and evaporation are reported in Table 2.

TABLE 2. MEAN VALUES FOR SWEAT PRODUCTION AND EVAPORATION
(SD in parentheses)

Ensemble	Sweat produced (L)		Sweat rate (L h^{-1})		Evaporation rate (L h^{-1})		Percent evaporation
Gentex	0.90	(0.17)	0.54	(0.10)	0.25	(0.06)	49
Current	0.99	(0.37)	0.59	(0.22)	0.22	(0.05)	39
Winfield	1.05	(0.27)	0.63	(0.16)	0.27	(0.05)	43

Ensemble effect did not show statistical significance at the $p < 0.05$ level for any of the sweat or evaporation parameters. Although not significant, subjects wearing the Gentex coverall produced slightly less sweat--of which more evaporated--than did those wearing the other ACDEs. However, since temperatures and heart rates were not affected, this finding is reduced in value. The sweat production and evaporation data are illustrated in Figure 11.

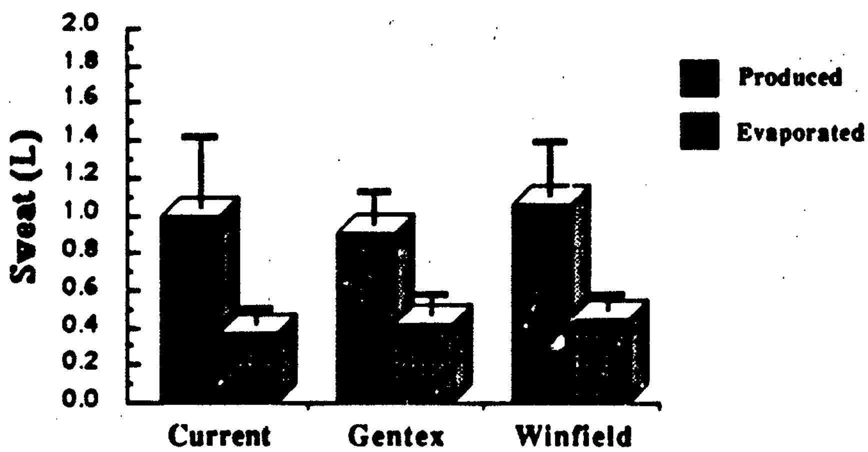

Figure 11. Ensemble mean (±SD) volumes of total sweat produced and evaporated.

DISCUSSION AND CONCLUSIONS

The objective of the present study was to evaluate, in humans, the thermal stress produced by each of two second-generation prototype ACDEs (Gentex and Winfield) and to compare this stress to that produced by the current ensemble under the same conditions.

Prior to the present study, copper-manikin evaluations of these two ACDEs were performed by the U.S. Army Research Institute of Environmental Medicine (USARIEM/SGRD-VE-ME) (2). Results of these previous studies indicated that the

candidate prototype ensembles showed a slightly better heat exchange capacity than the current ensemble, although the water vapor permeability capacity of the three suits was essentially the same. It appeared unlikely that a functional thermal advantage over the current ensemble would be realized by wearing either prototype candidate ensemble.

The present human thermal-stress-chamber evaluation confirms the interpretation of the manikin results. For all ensembles, group mean core temperatures and mean skin temperatures, as well as heart rates, followed similar pathways throughout the stress-profile evaluations. Sweat production and evaporation were also quite similar.

Statistical analysis failed to identify a significant difference in the parameters of interest among the ensembles. Additionally, graphic description demonstrated that the dependent variables responded quite similarly for all ACDEs throughout the experimental session.

In summary, within the limits and conditions under which this evaluation was conducted, the candidate second-generation aircrew chemical defense ensembles (Gentex or Winfield) did not offer any physiologic advantage in their thermal-stress-producing characteristics over the current ACDE.

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